# TRACKING COASTAL CHANGE IN AMERICAN SAMOA BY MAPPING LOCAL VERTICAL LAND MOTION WITH PS-INSAR

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## ABSTRACT

Characterizing diverse contributions to coastal land change is a key step to mitigating the effects of rising sea levels that threaten coastal communities. This task is particularly critical for small island communities in tectonically active regions, which are highly vulnerable to the effects of sea level rise. We highlight here a case study to extract regional estimates of vertical land motion (VLM) over American Samoa, which in recent years has observed increased nuisance flooding. We used persistent scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) to derive high-resolution estimates of crustal deformation in populated regions over Tutuila Island from 2015 to 2021. While the area is small and highly vegetated and poses challenges for InSAR, we were able to construct a regional map of the estimated deformation rate in these areas and validate the time-series with a local GPS station. Our preliminary results suggest that PS-InSAR has the ability to capture the local and regional deformation patterns, although further work is needed to compensate for more complex atmospheric effects, estimate error margins, and integrate our results into models of sea-level change that can be used local stakeholders.

***Index Terms—*** sea-level rise, coastal change, vertical land motion (VLM), interferometric synthetic aperture radar (InSAR), persistent scatterers

## 1. INTRODUCTION

Sea-level change presents increasing challenges to coastal communities. Rising waters can increase the incidence of minor and major flooding that threatens existing residences and cause damage to local infrastructure and other key resources. Such effects are particularly severe for island communities and states that have a large number of assets concentrated in coastal areas [1]–[3]. These problems can be further exacerbated in tectonically active regions since tectonic activity can lead to additional subsidence that further increases the relative sea level observed locally [4]. Accurately characterizing various local as well as global contributions to sea level rise in different regions is thus key to predicting future vertical land motion patterns and developing effective policies to minimize the damaging effects of floodwaters.

We focus here on American Samoa, an unincorporated US territory that is part of a volcanic archipelago in the Pacific, as a case study for characterizing local differences in vertical land motion. Tutuila Island, the largest and most populated island in American Samoa, underwent an increase in the rate of land subsidence due to post-seismic deformation following the Samoa-Tonga earthquake in 2009; it is predicted that nuisance flooding will occur regularly starting from the current decade [5]. However, there remains uncertainty about the Earth rheological properties that govern the timing and pattern of future subsidence in this region and the contribution of local as opposed to larger scale processes that govern the observed subsidence.

We study here the use of Interferometric Synthetic Aperture Radar (InSAR) for measuring local- vs. broad-scale VLM over Tutuila Island, which serves one key input for constraining alternative models of crustal deformation. InSAR is a remote sensing technique with high spatial resolution and moderate temporal resolution that spans several days to weeks in modern systems, depending on the constellation design. Advanced time-series InSAR techniques applied to high-quality data have measured crustal deformation down to accuracies of mm/yr in the line-of-sight (LOS) direction [6]–[8], which in practice is primarily vertical motion for spaceborne systems. However, even advanced InSAR time-series techniques can return less meaningful results over highly vegetated regions and isolated landmasses due to the larger unwrapping artifacts, complex atmospheric noise, and decorrelation noise introduced by such regions. As such, this has made applying InSAR more challenging over islands such as Tutuila. Here, we make a first pass at applying InSAR over the island and use the persistent scatterer InSAR (PS-InSAR) technique to limit contributions from highly vegetated regions and isolate our measurements to the more populated, well-correlated regions of Tutuila Island.

## 2. DATA AND METHODOLOGY

We processed Sentinel-1 data over Tutuila Island in American Samoa. Our study region is shown in Fig. 1 and covers most of the island; the inset shows the relative location of American Samoa in the Pacific Ocean. For this study, we have excluded the eastern side of the island to avoid an abrupt transition between swaths in the satellite acquisition that cuts

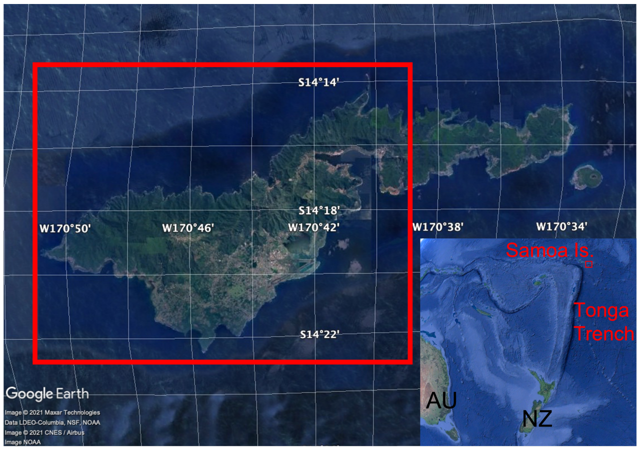


Fig. 1. Approximate study area outlined in red. Optical satellite imagery obtained through Google Earth. The inset shows the approximate location of the red square in the Pacific Ocean.

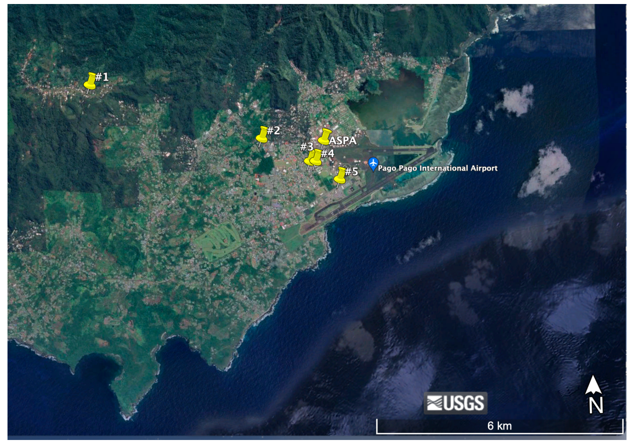


Fig. 2. Locations of the high-correlation reference points used as reference points in our study. Also marked are the locations of the GPS site, ASPA, and the Pago Pago International Aiport.

through the land mass. There is also a much lower density of coherent and phase-stable points on the eastern side of the island, which is primarily vegetated. We use all available data from December 20, 2014, to December 31, 2021 (path 51, frame 1133) in Interferometric Wide (IW) mode with a slant range resolution of 5 m and azimuth resolution of 20 m. The data are acquired at C-band (wavelength = 5.55 cm) with HH polarization. All data are publicly available through the European Space Agency (ESA) and can be accessed from the open archive managed by the Alaska Satellite Facility Distributed Active Archive Center (ASF DAAC).

We formed single look complex (SLC) images from Level-0 (L0) data using backprojection, which directly coregisters all images to our chosen digital elevation model (DEM) during focusing. The data are not multilooked once they are coregistered to the DEM. We use the Copernicus DEM, which has a resolution of 30 m over our area in the WGS84 reference coordinate system. The DEM is also available through ESA free-of-charge to any registered user. We chose a primary image for PS selection by minimizing the estimated decorrelation using the approach of Hooper [9], but in our study we disregarded the contributions from rotational decorrelation as the orbits are well-controlled for the Sentinel satellites. We applied the non-Gaussian maximum likelihood (NG MLE) PS detector described in [10]; this detector has been shown to operate well in mixed natural terrain. The detector requires takes the parameter alpha, which describes the heterogeneity of the region, and can be obtained by fitting the backscatter amplitude of one scene to the $G^0$ distribution; we obtain an alpha parameter of 2.973. We then deem PS all points with a signal-to-clutter ratio (SCR) above 3.1, an empirically chosen value for this region at which no more points in the ocean are identified as PS. The PS were applied as a mask to the set of non-redundant adjacent interferograms, which are then zero-interpolated and unwrapped using the SNAPHU algorithm [11]. Once the interferograms have been unwrapped, we de-ramped each scene in the stack by fitting a plane to the phases and subtracting the plane. We also applied a simple atmospheric correction by estimating elevation-based tropospheric contributions through fitting a linear trend to phase with elevation and then we removed the trend from the phase data. Finally, we referenced our measurements to a set of high-correlation points with the latitude and longitude locations shown in Fig. 2.

To obtain the estimated time-series signal, we averaged the signal from every point with the 20 closest PS. Then, to create the overall deformation map, we calculated a simple estimate of the deformation rate at each PS by computing the difference between the first and last scenes for each averaged PS and divided by the total time period.

As a form of validation, we compared the estimated deformation from PS-InSAR at one point with continuous GPS measurements from the nearby ASPA station (latitude = -14.326, longitude = -170.722), using the fixed-plate solutions available from the University of Nevada Geodetic Laboratory [12].

## 4. RESULTS AND DISCUSSION

A map of estimated vertical deformation rates around the island is shown in Fig. 3, overlaid on the average amplitude backscatter. We see that the runways at the Pago Pago International Airport are clearly outlined and appear to be subsiding significantly compared to the other parts of the island further north or inland, which by comparison are measured to be uplifting. We note that there appears to be a slight gradient across the map that could be due partly to uncorrected atmospheric or topographic signals. Additionally, our reference points are primarily clustered near the airport, thus biasing our InSAR measurements to that region. Further comparing our measurements to tide-gauge measurements could help elucidate whether there are spatially correlated biases in our InSAR data. The region is

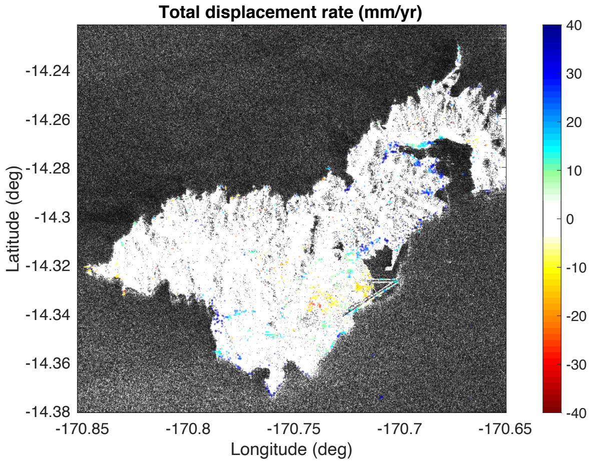


Fig. 3. Vertical deformation map of Tutila Island overlaid on amplitude image. Average rate of deformation shown in mm/yr.

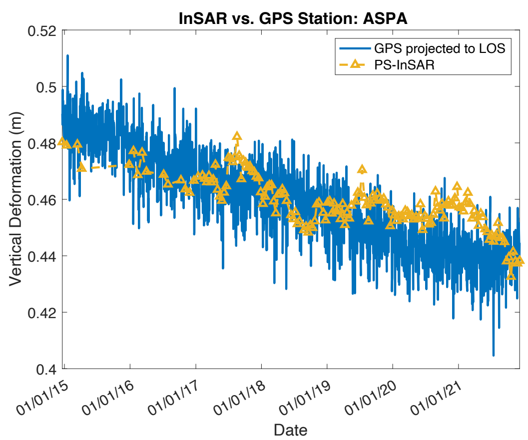


Fig. 4. Time-series of cumulative vertical deformation from December 20, 2014, to December 7, 2021, derived from GPS (blue, solid line) and PS-InSAR (dotted line with triangles).

also likely more atmospherically complex than our simple tropospheric correction scheme can account for, which could add additional noise.

The InSAR-derived time-series compared with the ASPA GPS station is shown in Fig. 4. We see that there is a strong oscillatory signal that appears to be seasonal in nature, which could further suggest uncorrected atmospheric contributions or simply seasonal land motion due to water loading. Still, we overall observe that the trend of the InSAR time-series generally tracks the vertical deformation of the GPS station over time, which suggests that PS-InSAR is able to detect some of the regional deformation trends in the area.

## 5. CONCLUSION

Our initial results show that we are able to derive an estimate of regional differences in land subsidence over Tutuila Island with PS-InSAR. Further work is needed to denoise the time-series and better understand the regional differences around the island by comparing our results with additional data such as tide-gauge measurements in Pago Pago harbor. Further work will also focus on incorporating existing tools for data correction that rely on advanced tropospheric models. Accurate InSAR measurements can thus be incorporated with other geodetic measurements to provide a better understanding of local differences in VLM and shed light on expected patterns of future subsidence in the region, enabling local policymakers to make decisions about combatting the negative effects of rising sea levels.

## 6. ACKNOWLEDGEMENTS


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